National Aeronautics and Space Administration
Goddard Space Flight Center
Contract No. NAS-5-9299

ST - PF - 10 477

PITCH-DISTRIBUTION OF PROTONS ORIGINATING FROM AURORAE

by

O. L. Vaysberg

(USSR)

18 APRIL 1966

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Geomagnetizm i Aeronomiya
Tom 6, No. 1, 135 - 7,
Izdatel'stvo "NAUKA", 1966.

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SUMMARY

Although the present state of knowledge of angular and energetic characteristics of soft protons is still little advanced and requires further research with the aid of AES, particularly in regard to their intrusion mechanism, it is tentatively concluded on the basis of what is known, that the basic mass of aurora protons undergoes no acceleration in the geomagnetic field.

* * * * *

The detection by Vegard [1] in 1939 of hydrogen emission in aurorae constituted the first evidence of corpuscular intrusion into the upper atmosphere. Doppler shift of Balmer lines was revealed in the works [2, 3]. Analysis of the magnitude of that shift on the basis of the prevailing representations on the effective cross sections had led I. S. Shklovskiy to the conclusions [4, 5] that the atmosphere-intruding protons have a broad velocity spectrum with maximum in the vicinity of 1000 km/sec. Subsequently, attempts were made to explain the profiles of hydrogen lines by a specially assorted angular distribution for the intruding monoenergetic protons [6, 7]; however, Omholt has shown [8] that such a method does not provide the possibility of coordinating the profiles of hydrogen lines observed in the magnetic zenith (along the line of force) and in the magnetic horizon (perpendicularly to the line of force).

Disposing of a more complete material, Chamberlain [9] and Yu. I. Gal'perin [10] reached the conclusion on the necessity to postulate that

* O PITCH-RASPREDELENII PROTONOV POLYARNYKH SIYANIY.

part of the intruding protons have comparatively low velocities. A more detailed analysis of hydrogen line profiles has shown [11] that in the velocity region of the order of several hundred km/sec ($1-5$ kev) the differential energy spectrum varies as $E_0^{-1.8}$, where E_0 is the initial proton energy. At the same time a different approach to profile analysis leads to different representations on the stretching of the angular distribution from $n=0$ to $n=6$, if its dependence on the pitch-angle α is represented in the form $\cos^n\alpha$ [11, 12]. These contradictory results can not be explained only by the low precision in the determination of the shapes of line profiles by observations. Apparently, we have to deny ourselves the possibility of assuming the independence of angular and energy distribution of aurora protons that was made when analyzing the hydrogen emission [9 – 13]. Even if protons do not undergo notable scatter at deceleration in the atmosphere [11 – 13], there is no basis to estimate that the angular distribution of intruding protons does not depend on their energy.

The emission intensity $I(u,\varphi)\,du$ in the wavelength range $(\lambda, \lambda + d\lambda)$ or in the corresponding Doppler velocity interval $(u, u + du)$ at observation under the angle φ to the magnetic line of force constitutes a plane distribution cross section of emitting hydrogen atoms in the velocity space (taking into account the deexcitation effectiveness)

$$I(u, \varphi)\, du = 2du \int\limits_{v=u}^{\infty} \int\limits_{\alpha=\varphi-\arccos u/v}^{\alpha=\varphi+\arccos u/v} \frac{j(v, \alpha) F(v)\, v \sin\alpha}{\left(\sin^2\varphi - \cos^2\alpha + 2\dfrac{u}{v}\cos\alpha\cos\varphi - \dfrac{u^2}{v^2}\right)^{1/2}}\, dv\, d\alpha,$$

where $f(v, \alpha)$ is the directed flux of emitting hydrogen atoms, with velocity v and at the angle α to the line force (in $cm^{-2}\ sec^{-1}\ ster^{-1}$). Every atom enters into the observed intensity with a weight $F(v)$, which is the probablity of a quantum emission in the given velocity range. This strict expression may be simplified provided $f(v, \alpha)$ may be represented in the finite series

$$j(v, \alpha) = \sum_{n=0}^{N} A_n(v) \cos^n\alpha.$$

Then the integration over α is performed in quadratures and

$$I(u, \varphi) = 2\pi \int\limits_{u}^{\infty} \sum_{n=0}^{N} v A_n(v) F(v) K_n\left(\cos\varphi, \frac{u}{v}\right) dv,$$

where $K_n(\cos\varphi, u/v)$ are polynomials of power $n-1$ relative to $\cos\varphi$ and u/v. The Volterra equation of first kind (3) was resolved numerically relative to functions $B_n(v) = vA_n(v)F(v)$. Limiting ourselves to the sixth power in the expansion (2), $N = 6$, that is, estimating that $f(v, \alpha)$ is not a very sharp function of α, it is sufficient to take the values of $I(u, \varphi)$ for seven values of φ: 0, 30, 60, 90, 120, 150, 180°. The upper limit in the equation (3) may be replaced by U, where U is determined from the condition $I(u > U, \varphi) = 0$.

The values of $I(u, \varphi)$ were taken by the aurora spectra obtained at the Loparsk station by photoelectric method during the winter of 1959/1960 [14]. The hydrogen emission is radiated in the so-called hydrogen field, which is a rather uniform band of 100 – 1000 km width, approximately stretched along the magnetic parallel [14, 15]. The conditions of observations do not allow to obtain profiles separately for different heights, and this is why the data on energetic and angular characteristics of emitting hydrogen atoms, drawn from the hydrogen line profiles, are integral and related to the entire thickness of the atmosphere where deceleration takes place, that is, for protons invading the thick target. The profiles for the lines H_β for various φ were normalized by the condition that hydrogen atoms emit isotropically. The effect of light scattering on the shape of line profiles was not taken into account, for the observations were conducted during nights with satisfactory transparency and the estimates of scattered light show, according to [16], that its influence lies within the range of accuracy of observations. The profile of H_β utilized at computations, is somewhat wider in the magnetic horizon ($\varphi = 90°$) tha those that are known from published data.

Thus, resolving the equation (3) we obtain the product of the function (2) searched for, by the probability of emission in the given interval of velocities $F(v)$. Evidently, the angular characteristics of the distribution of protons, reworked in the atmosphere, may be obtained from the solution even if, generally speaking, we are unaware of the form of the function $F(v)$. The character of the dependence of the directed intensity on the angle for three values of energy ($1 - E \leqslant 1$, $2 - E = 3$, $3 - E = 20$ kev) is represented in Fig. 1. The intensity variation with the angle for the considered energy range varies more slowly than $\cos^6\alpha$; this is why the representation of $f(v, \alpha)$ in the form (2) at $N = 6$ may be considered justified.

The dashes in Fig. 1 indicate the pitch-distribution of protons with energy 20 kev, which they would have on the equator if their motion along the line of force were not distorted by the influence of the electric field. Protons of lower energies also have a very narrow equatorial pitch-distribution. The following function, brought out by Chamberlain [11],

$$F(v) = K \frac{v^2}{\beta^2} e^{-v^2/\beta^2},$$

was taken for the function F (v) ; it represents the number of emitted Balmer quanta per unitary interval of velocity variation. It was computed from the condition of statistical equilibrium according to the available theoretical and experimental cross sections [11]; at the same time the basic contribution in (4) is given by proton charge exchange with atmosphere atoms and molecules on the level considered and the excitation of neutralized hydrogen atoms. Integrating the computed function

$$\frac{1}{v} \sum_{0}^{6} B_n(v) \cos^n \alpha$$

over pitch-angles and utilizing the expression (4), we obtain j (v), which constitutes the number of hydrogen atoms, reworked in the atmosphere, which pass at deceleration the unitary velocity interval. Taking advantage of the conservation condition, that is, of the fact that the intruded proton will be decelerated in the atmosphere to zero velocity and that the fraction of protons, leaking from the atmosphere, will not be great, it is possible to obtain the differential spectrum of protons. It is plotted in Fig. 2.

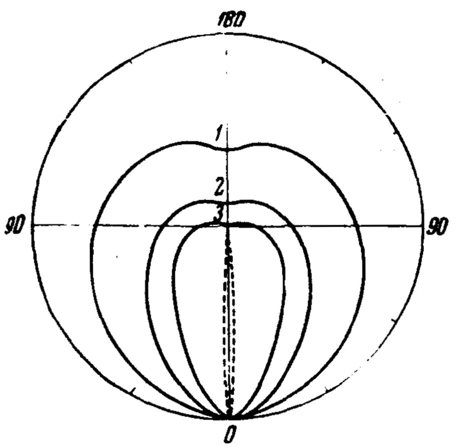

Fig. 1

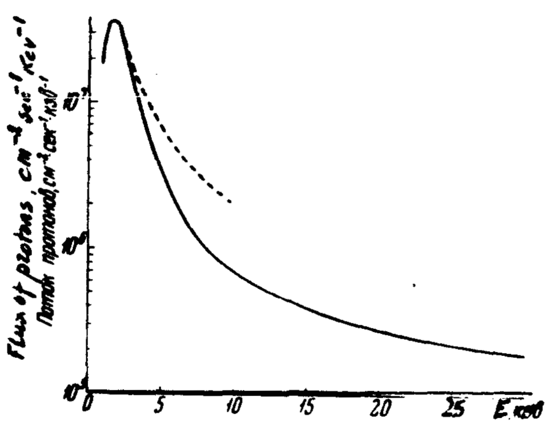

Fig. 2

The spectrum normalization corresponds to line H_β intensity equal to 100 rayleighs, which is standard for the hydrogen field [14]. The dotted line shows the spectrum obtained in the assumption of independence of angular and energetic distribution of protons [11]. It may be seen that the rejection of this assumption changes substantially the form of the energy spectrum; thus, the spectrum of [11] has the form $E_o^{-1.8}$, while that obtained from the equation (3) varies as $E_o^{-2.7}$ in the energy range 1 — 5 kev. If the form of the excitation function is correct (4), it follows from the comparison of Figs. 1 and 2 that the low-energy protons ($E \lesssim 3$ kev) undergo a strong scattering in the atmosphere. However, such a conclusion is preliminary until reliable experimental cross sections are obtained for energies of less than 5 kev. It is apparently premature to derive the conclusion of the presence or absence of anisotropy dependence on energy for an intruding bunch of protons. However, if proton capturing on geomagnetic lines of force takes place at sufficiently great distances, only those protons are trapped which have velocities nearly exactly along the line of force (Fig. 1). Comparison of the obtained maximum of $f(v)$ at $v \sim 650$ km/sec with the data on solar wind [17] shows a good accord. This compels us to assume that the basic mass of protons from aurorae undergoes no acceleration in the geomagnetic field. The study of angular and energetic characteristics of soft protons with the help of artificial satellites will allow the clarification of their intrusion mechanism.

*** THE END ***

Institute of Atmosphere Physics
of the
USSR Academy of Sciences

Manuscript
received
on 7 May 1965.

Contract No.NAS-5-9299
Consultants and Designers, Inc.
Arlington, Virginia

Translated by ANDRE L. BRICHANT
on 17 April 1966

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